

NASA TT F-11,401

CHANGES IN THE TOLERANCE OF MAN TO TRANSVERSE ACCELERATIONS

A. R. Kotovskaya, R. A. Vartbaronov
and S. F. Simpura

Translation of "Izmeneniye perenosimosti chelovekom
poperechnykh peregruzok posle gipodinamii razlichnoy
prodolzhitel'nosti". Report at the Eighteenth Con-
gress of the International Astronautical Federation,
Belgrade, 25-30 September 1967

FACILITY FORM 602	N68-16830	
	(ACCESSION NUMBER)	(THRU)
	13	
	(PAGES)	(CODE)
	✓	04
	(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON

DECEMBER 1967

TTF-11,401

CHANGES IN THE TOLERANCE OF MAN TO TRANSVERSE ACCELERATIONS

A. R. Kotovskaya, R. A. Vartbaronov
and S. F. Simpura

/1

Space flights have given rise to a number of problems, one of which is a study of human tolerance to accelerations in the period of return to earth after a prolonged state of weightlessness has been experienced. The investigations made for clarifying this extremely complex problem are of great scientific and practical interest.

In fact, in implementing a space research program it is necessary to have a clear idea of what effect prolonged weightlessness may exert on man. The formulation of predictions obviously must be based both on a study of the experience obtained both in flights and in laboratory experiments in which the corresponding weightlessness effects are simulated. It is known that immersion in water and a prolonged stay in a horizontal position with limited mobility are forms of laboratory simulation which can be used for evaluating the effect of weightlessness on human tolerance to accelerations.

Orbital flights have demonstrated that cosmonauts are capable of enduring weightlessness for up to 14 days. However, these investigations at the same time have revealed some unfavorable changes in a number of organs and systems in the /2 cosmonaut's body, indicating a decrease of the functional tolerance of the human body after orbital flight (N. M. Sisakyan, 1964; O. G. Gazenko, 1964, 1965; Lamb, et al, 1964; Berry, 1966; Taylor, et al, 1966).

After flight with a duration greater than one day there were symptoms of dehydration, demineralization and some other impairments (N. M. Sisakyan, et al, 1964; Berry, 1966).

In laboratory experiments many investigators have noted

similar changes in the functional state of different systems of the body (L. I. Kakurin, Yu. N. Tokarev, 1962; L. I. Kakurin, et al, 1966; Yu. V. Vanyushina, 1963; Deitrick, et al, 1948; Taylor, et al, 1949; Graveline, 1952; Miller, 1964; Potts, Bowring, 1960; Bronnon, et al, 1963, and others).

Data on the effect of prolonged hypodynamia or immersion in a liquid on tolerance to overloads, deterioration of the tolerance to the effect of longitudinal ($+G_z$) and transverse ($+G_x$) accelerations, as well as orthostatic tests, noted by virtually all investigators working in this field (A. R. Kotovskaya, L. I. Kakurin, et al, 1964; P. V. Vasil'yev, A. R. Kotovskaya, 1965; Graveline, Barnard, 1961; Graveline, 1962; David, 1961; Miller, Leverett, 1965) are of particular interest.

In model experiments investigations have been made of the tolerance of man to accelerations ($+G_x$) with maximum durations of hypodynamia up to 20 days (A. R. Kotovskaya, et al, 1964, 1967) and 28 days (Miller, Leverett, 1965). Tolerance to 3 overloads has not been studied for hypodynamia of long duration. However, it is of considerable interest to trace the change of tolerance to the effects of acceleration for hypodynamia of different duration. For this reason we felt it justifiable to carry out new experiments with subjects who were exposed to conditions of hypodynamia of different duration.

We believe that the solution of these problems will make it possible to obtain data for a more complete forecasting of the condition of a cosmonaut in the final part of the flight during return to earth as a function of its different duration.

This paper generalizes the investigations devoted to the problem of human tolerance to transverse accelerations after hypodynamia under conditions of a strict bed regime with a duration of 3.7-20 and 60 days now at our disposal. Experiments on hypodynamia have been carried out by L. I. Kukurin, V. I. Slesarev and other investigators.

The experiments were carried out with the participation of 20 healthy individuals who had been subjected to a special clinical examination. Tolerance was evaluated on the basis of the maximum magnitude of acceleration acting in a chest-back direction ($+G_x$) at an angle of 80° and 65° . The principal criterion of tolerance under the influence of accelerations at an angle of 80° was the appearance of relative bradycardia, less frequently visual and respiratory disorders, whereas at an angle of 65° it was primarily visual disorders.

The collected data on the tolerance to accelerations and physiological reactions were statistically processed by the differences method using the linear unidirectional regression technique. In addition, the indices of the physiological reaction of the subjects were compared as a result of the imparting of accelerations of different magnitude with respect to their absolute values and with the initial levels taken into account. The results of investigation of tolerance to accelerations after hypodynamia are shown in Fig. 1. 4

This figure shows that the tolerance to accelerations after a 3-day stay in bed did not change in comparison with the initial level.

A gradual decrease of tolerance to accelerations was observed after hypodynamia lasting 7 days. After a 15-20-day stay in bed this decrease averaged 2.4 units. After a two-month period of hypodynamia the tolerance to accelerations was at approximately the same level as after a 15-20-day period of hypodynamia (2.2 units). Therefore, after a 15-20 day stay in bed there was no further reduction of tolerance; the tolerance to accelerations was stabilized at approximately the same level (2.2-2.4 units less than the initial level). The stabilization of the curve also is confirmed by the statistical unreliability of the regression coefficient for hypodynamia with a duration from 15-20 to 60 days.

Restoration of initial tolerance appeared in all the subjects 17-50 days after termination of a 2-month period of hypodynamia.

Similar data were obtained in an investigation of the reaction of the cardiovascular and respiratory systems to acceleration. Table 1 gives the frequency of cardiac contractions in subjects in the initial state prior to rotation and also under the influence of accelerations before and after hypodynamia of different duration. 5

For greater reliability of the noted changes the change of the frequency of cardiac contractions in the subjects (14 men) in the initial state and under the influence of accelerations of 8 and 10 g at the time of background tests prior to hypodynamia (special mean) was compared with the heartbeat rhythm of a large group of persons (66 subjects) who had not participated in the experiments (general mean). It was found that the reaction of cardiac activity in the subjects of the experimental group in the experiments on the centrifuge prior to hypodynamia was the same as for subjects who had not participated in the experiment.

Table 1 shows that after a stay under conditions of a strict bed confinement in the initial state prior to the imparting of accelerations there was an appreciable quickening of the rhythm of cardiac activity and the clarity of expression of this quickening increased with a lengthening of the duration of the hypodynamia. It may be assumed that nervous and emotional stress, causing this change of cardiac activity because of the impending rotation on the centrifuge, increased with an increase of the duration of hypodynamia. 6

Table 1

Frequency of Cardiac Contractions Under the Influence of Accelerations Before and After Hypodynamia, beats/min

Period of study	Initial data		After hypodynamia with duration		
	General mean (66 men)	Special mean (14 men)	7-12 days	15-20 days	60 days
5 min before	76±1	76±3	84±10	88±8	91±6*
1 min before	85±2	86±3	90±15	102±11	105±8*
During 8g acceleration	124±2	125±4	147±14	158±9**	158±11*
During 10g acceleration	128±2	132±5	150±24	162±8**	164±8**

Notes: 1. The table gives the mean values, mean error and the significance level in comparison with the background. * -- 0.05, ** -- 0.01.

2. In investigations on the centrifuge the angle of inclination of the back of the seat in all cases was 80° to the acceleration vector.

Thus, whereas the frequency of cardiac contractions a minute prior to the imparting of accelerations after a 7-12-day hypodynamia was 90 beats/min, after 15-20- and 60-day periods of hypodynamia it increased to 102-105 beats/min. Prior to rotation the pulse rate was 86 beats/min. Under the influence of accelerations after hypodynamia the heartbeat frequency differed from the initial values. For example, after a 7-12-day bedstay the pulse rate under the influence of an acceleration of 8 g was 147 beats/min, and after a 15-20-day hypodynamia it increased to 158 beats/min. Then, after a 50-day hypodynamia the heartbeat frequency did not change -- 158 beats/min. Under the influence of an acceleration of the same magnitude at the time of the initial test it was at

the level 125 beats/min.

The dynamics of the change of the reaction of the cardiovascular system, evaluated from the increase of the frequency of cardiac contractions under the influence of accelerations of 8 and 10 g, is shown in Fig. 2.

Fig. 2 shows that in the first 7-12 days of hypodynamia there was a gradual increase in the reactivity of the cardiovascular system to acceleration. After 15-20 days the increase of the pulse rate averaged $+31 \pm 16$ beats/min. We note that after a 60-day period of hypodynamia the average increase of the frequency of cardiac contractions was the same as after a 15-20-day bedstay ($+31 \pm 16$). It is interesting to note that according to the data of the American scientists Miller and Leverett, after a 4-week period of hypodynamia the quickening of the pulse under the influence of an acceleration of 10.6 g also was the extremely close value $+33 \pm 20$ beats/min. Therefore, the differences in the increase of the pulse rate after hypodynamia lasting 15-20, 28 and 60 days were virtually nonexistent. It may be assumed that after a 15-20 day bed-^{/8} stay a period of definite stabilization in the reactions of the cardiovascular system to the influence of accelerations sets in.

The reactivity of the respiratory system was evaluated from the increase of the oxygen debt and lung ventilation after termination of rotation (Fig. 3). It was established that after a three-day period of hypodynamia there were no reliable changes of the indices of external respiration in comparison with the background rotation. However, after 15-20- and 60-day bedstays the difference in the change of lung ventilation and the oxygen debt was considerable in comparison with the initial effect. For example, the additional increase of lung ventilation in the period of the aftereffect to accelerations prior to hypodynamia was 17.3 liters, after a 15-20-day period of hypodynamia it was 43.8 liters (that is, the difference of the increments was an average of 26.5 liters) and after a 60-day period of hypodynamia it was 23.3 liters.

Thus, the clarity of expression of the reaction of the respiratory system with respect to lung ventilation was approximately identical after 15-20- and 60-day bedstays (Fig. 3). The mean values of the maximum endured accelerations before and after 15-20- and 60-day periods of hypodynamia were close (the average difference was 0.8 g).

Since our investigations were made with the participation of a limited number of subjects (10 persons), for great-

er reliability of the determinations of the changes the data for lung ventilation and the oxygen debt obtained for the subjects of the experimental group were compared with the data for a group of subjects (33 persons) not participating in the experiments with hypodynamia. The conditions of exposure to accelerations were identical.

We compared the changes for each subject separately with the appropriate values for lung ventilation and the oxygen debt for the corresponding acceleration to which they were subjected. The data are given in Table 2.

The data in Table 2 show that it was impossible to detect a reliable change of lung ventilation after a 15-20 day period of hypodynamia in comparison with a 60-day period. The difference in the increments of this index after the mentioned periods of hypodynamia was extremely close.

Thus, the prolonged presence of man in a horizontal position with limitation of his mobility resulted in a decrease of the tolerance to transverse accelerations. Attainment of equivalent magnitudes of acceleration was accompanied by considerably higher functional stress of the physiological systems of the body. The change of tolerance to accelerations after different periods of hypodynamia was different.

For example, after a 3-day period of hypodynamia the human tolerance to accelerations virtually did not differ from the initial level. With an increase of the duration of hypodynamia there was a decrease of tolerance. After a 15-20-day bedstay it averaged -2.4 units. However, after a 60-day period of hypodynamia this decrease was virtually the same as after a 15-20-day period of hypodynamia (2.2 units). The reactivity of the physiological systems under the influence of accelerations after these periods of hypodynamia also was approximately identical. /11

Accordingly, these data indicate that in the case of hypodynamia with a duration of 15-20 and 60 days there was no reliable dependence between the degree of decrease of tolerance, the reactivity of the body and the duration of bed confinement.

We feel that these data are indicative of the development of a process of singular adaptation to conditions of prolonged (up to 2 months) hypodynamia, beginning approximately on the 15th-20th day of a severe bed confinement regime. Experimental data confirming this point of view were obtained in the experiments of L. I. Kakurin, M. A. Cherepakhin, E. S. Kat-

Physio- logical indices	Before hypodynamia		After 3-day hypodynamia		Before hypodynamia	
	A	B	A	B	A	B
Oxygen debt, in ml	21±80	+85±107	-6±15	-	-	-
Increment of lung ventila- tion, in l	2.8±3.3	+0.4±3.3	-0.2±1.8	32±3.2	-13.2±5.9*	

Physio- logical indices	After 15-20 days of hypodynamia		Before hypodynamia		After 60-day period of hypodynamia	
	A	B	A	E	A	B
Oxygen debt, in ml	-	-	788±76	-144±68	698±78	+682±246**
Increment of lung ventila- tion, in l	25.9±2.7	+20.9±6.6**	25.9±2.7	-3.6±3.9	21.4±2.9	+23.2±9.4*

Notes: 1. The general mean was determined on the basis of absolute data on external respiration for 33 subjects.
 2. The special mean gives the deviations of the actual values of the indicated indices from the corresponding data obtained taking into account the accelerations imparted in each specific case.
 3. The reliability of the differences was determined by comparison with the general mean: * -- more than 0.95; ** -- more than 0.99.

A) General mean; B) Special mean

ovskiy, G. I. Kozyrevskaya, and others (1967). It has been established by the authors that in the course of a 2-month period of hypodynamia in its second half there is a gradual normalization of a number of indices of water and mineral metabolism, the blood system and other systems of the body. For example, according to the data of G. I. Kozyrevskaya (1967) the maximum release of electrolytes (K, Na, Ca, P) was observed in the third-fourth week of hypodynamia; then this release decreased and by the end of the 60-day experiment attained the initial values. Similar data were obtained concerning a number of other indices.

Thus, the results of investigations make it possible to assume that with respect to tolerance to accelerations in the course of hypodynamia there are two phases of change of the reactivity of the body: the first phase, with a duration of 15-20 days, is characterized by a gradual decrease of tolerance to accelerations and an intensification of the clarity of expression of the reactions of the body; the second phase is stabilization, when the reaction of the body and the tolerance to accelerations are maintained at the attained level, corresponding to the 15th-20th day of the hypodynamia.

The possibility of extrapolation of the data obtained for a state of hypodynamia to the conditions of weightlessness in space flight is of unquestionable interest.

According to the reports of a number of investigators (Berry, 1966; Taylor, 1966 and others), during space flights the cosmonauts experienced a reduction of orthostatic tolerance, beginning with a 34-hour stay in a state of weightlessness. However, after a 14-day flight changes of orthostatic tolerance were even less clearly expressed than after an 8-day flight.

Therefore, during prolonged orbital flights Berry and other investigators feel that cosmonauts undergo adaptation to the conditions of weightlessness. In actuality, in multi-day flights of man and animals O. G. Gazenko, N. M. Sisakyan and others (1964) observed manifestations of a certain adaptation to the effect of weightlessness, evaluated from everyday reactions and the state of the most important physiological systems.

Proceeding on the basis of general biological premises, some authors feel that mechanisms of adaptation must be included in the general reactions of the body to weightlessness, making it possible to reduce to a minimum the unfavorable effects of this factor (Yu. M. Volynkin, P. P. Saksonov, 1964;

V. V. Parin, V. I. Yazdovskiy, 1962; L. I. Kakurin, B. S. Katovskiy, 1962; L. I. Kakurin, B. S. Katovskiy, et al, 1966).

Thus, the experimental data which we obtained, as well as data in the literature, apparently indicate the existence of general mechanisms of the adaptation of the human body to conditions of weightlessness and hypodynamia.

References

- Vasil'yev, P. V. and Kotovskaya, A. R.: XVI International Astronautical Congress, Athens, 1965 (XVI Mezhdunarodnyy Astronavticheskiy Kongress, Afiny, 1965).
- Vanyushina, Yu. V., IN: Aviation and Space Medicine (Aviatsionnaya i kosmicheskaya meditsina), Moscow, 1963, 92.
- Volynkin, Yu. M. and Saksonov, P. P.: Problems in Space Biology (Problemy kosmicheskoy biologii), Izd-vo "Nauka", Vol. 3, 10, 1965.
- Volynkin, Yu. M., Parin, V. V. and Yazdovskiy, V. I.: Problems of Space Biology (Problemy kosmicheskoy biologii), Izd-vo "Nauka", Vol. 2, 7, 1965.
- Gazenko, O. G.: Third International Symposium on Bioastronautics (Tretiy Mezhdunarodnyy Simpozium po Bioastronavtike), San Antonio, November, 1964.
- Gazenko, O. G. and Gyurdzhian, A. A.: Sixth International Symposium on the Space Sciences (Shestoy Mezhdunarodnyy Simpozium po Kosmicheskim Naukam), Buenos Aires, May 1965.
- Sisakyan, N. M., et al: The First Group Space Flight (Pervyy gruppovoy kosmicheskoy polet), Izd-vo "Nauka", Moscow, 1964.
- Kakurin, L. I. and Tokarev, Yu. N.: Summaries of Reports at the Scientific Session Dedicated to the Fifth Anniversary of Launching of the First Artificial Earth Satellite (Tezisy dokladov na nauchnoy sessii, posvyashchennoy 5-y godovshchine zapuska pervogo iskusstvennogo sputnika Zemli), 1962.
- Kakurin, L. I., Katovskiy, B. S., Cherepakhin, M. A. and Sinkovich, Yu. A.: IN: Aviation and Space Medicine (Aviatsionnaya i kosmicheskaya meditsina), Moscow, 1963, p. 382.
- Kakurin, L. I., Akhrem-Akhremovich, R. M., et al: IN:

Materials of the Conference on Space Biology and Medicine (Materialy konferentsii po kosmicheskoy biologii i meditsine), Moscow, 1966, p. 11.

Kakurin, L. I. and Katovskiy, B. S.: IN: Physiology of Man and Animals (Fiziologiya cheloveka i zhivotnykh), Izd-vo AN SSSR, Institute of Scientific Information, Moscow, 1966, pp. 6-29.

Kovyrevskaya, G. I., Kakurin, L. I., Biryukov, Ye. N., Koloskova, Yu. S., Pak, Z. P., and Chikhov, S. V.: Space Biology and Medicine (Kosmicheskaya Biologiya i Meditsina), 1967, 2, p. 74.

Kotovskaya, A. R., Kakurin, L. I., et al: Summaries of the Scientific Reports at the Tenth Congress of the All-Union Physiological Society (Tezisy nauchnogo soobshcheniya 10 s"yezda Vsesoyuznogo fiziologicheskogo obshchestva), Moscow-Leningrad, 2, I, 1964, 421.

Kotovskaya, A. R., Kakurin, L. I., Konnova, N. I., Simpura, S. F. and Grishina, I. S.: Problems of Space Biology (Problemy kosmicheskoy biologii), Izd-vo "Nauka", Vol. 4, 1965, p. 333.

Kotovskaya, A. R., Vartbaronov, R. A. and Simpura, S. F.: Problems of Space Biology (Problemy kosmicheskoy biologii), Izd-vo "Nauka", Vol. 6, 1967.

Parin, V. V. and Yazdovskiy, V. I.: Fiziologicheskiy Zhurnal SSSR, No. 10, 1961, p. 1217.

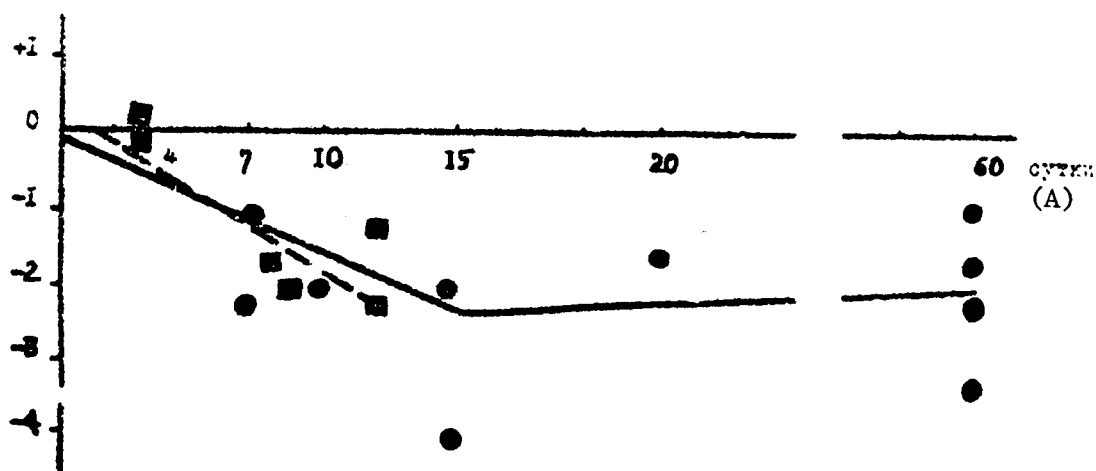


FIG. 1

FIGURE CAPTIONS

Fig. 1. Change of tolerance to transverse accelerations as a function of the duration of hypodynamia: the dots represent individual cases of the difference of the maximum endurable magnitudes of accelerations with inclination of back of seat of 10° ; the squares represent an angle of 25° to the horizontal.

Fig. 2. Change of frequency of cardiac contractions under the influence of accelerations of 8 and 10 g after hypodynamia of different duration. Angle of inclination of back of seat was 80° from acceleration vector.

Fig. 3. Changes of lung ventilation (filled squares) and oxygen debt (open squares) after imparting of maximum endurable accelerations as function of duration of hypodynamia.

A) Days; B) beats/min; C) Pulse rate; D) at 8-g level; E) at 10-g level; F) Duration of hypodynamia; G) Lung ventilation; H) Oxygen debt

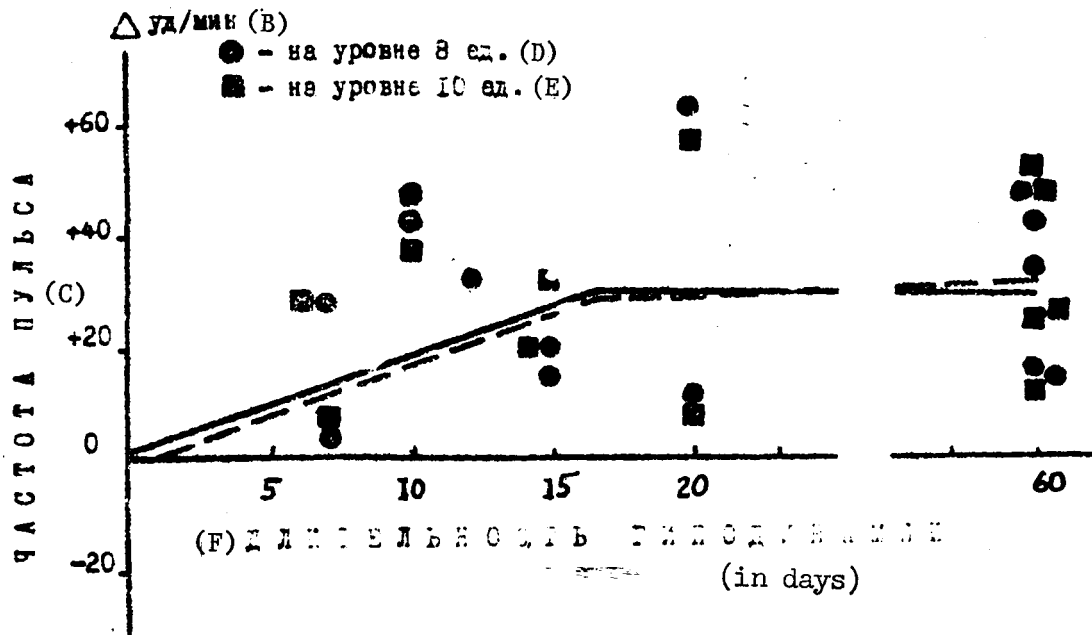


FIG. 2

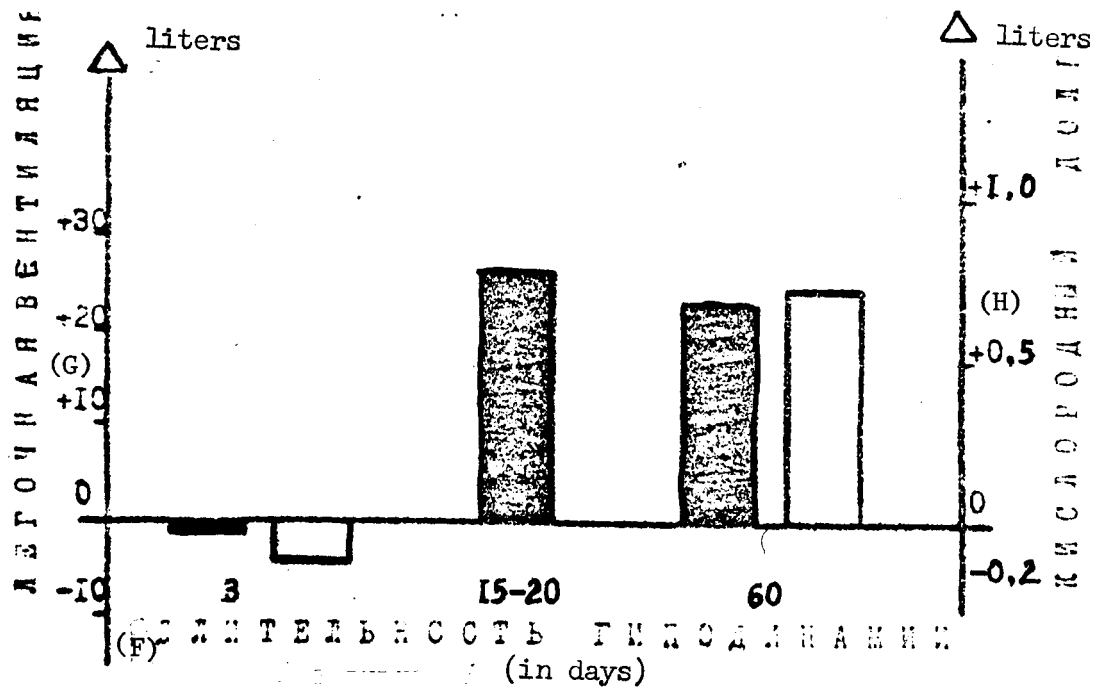


FIG. 3